Semi-Annual Report
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Task Objectives

The overall objectives of the MODIS snow project are to: develop and test algorithms to map snow extent and reflectance using MODIS data, to assess quantitatively, the errors associated with snow mapping using our algorithm, and to analyze spatial and temporal variability in the bidirectional, reflected solar and emitted thermal radiances over snow- and ice-covered areas to improve the current understanding of the role of snow and ice cover as key components of the global energy balance.

Work Accomplished

Summary. Work has been accomplished in two primary areas of research: development of the snow-mapping algorithm, and analysis of snow reflectance. In support of those areas of research, field work was conducted in December 1992. The MODIS/snow project is now actively participating in BOREAS, through two separate, but related, projects that are recognized and accepted by NASA Headquarters. Three presentations were given on snow-mapping algorithm development, and 1 paper was published. Two abstracts have been submitted for publication and presentation at the Eastern Snow Conference. MODIS and BOREAS meetings have been attended. Dr. Glen Liston/USRA (Code 913) has begun to work on MODIS-related activities. Details concerning the above-cited topics are discussed below.

Development of the snow-mapping algorithm

Progress has been made in our ability to map snow using an algorithm that has been developed using TM data as a surrogate for MODIS data. A flow diagram showing the current algorithm is shown in Figure 1.

Until recently, the snow mapping algorithm had only been applied to snow-covered mountainous areas in Alaska. Thus it had not been tested under conditions of mixed snow and vegetation. Mixed land covers comprise much of the snow-covered areas of the Northern

Hemisphere and thus it is important to asses the utility of the algorithm for mapping snow over these sites. A 15 March 1991 TM scene of Glacier National Park, Montana was selected for study because: 1) the area was snow-covered, 2) field measurements had been acquired near the time of the Landsat overpass, and 3) the site is comprised of a variety of land covers, from deciduous to coniferous forests, to prairie and mountains. The revised snow-cover mapping algorithm was applied to the Glacier National Park TM scene. Results indicate that the algorithm does an adequate job of mapping the snow on that TM scene. To begin to address the errors using our snow-mapping algorithm, we plan to compare the results of our derived snow maps with air photos that were acquired by the C-130 aircraft during an overflight that took place on 14 March 1991. We will also obtain NOAA AVHRR data of the area and compare snow-covered areas as mapped using our algorithm and the NOAA data. Dr. Jim Tucker/923 has agreed to provide us with the required NOAA data.

MODIS Airborne Simulator (MAS) data were obtained over the Sierra Nevada Mts. in November, 1991. Preliminary analysis of the MAS data was reported on in the last semi-annual report, and a paper was written and accepted for publication in the <u>Proceedings of the 49th Annual Eastern Snow Conference</u>. Since that time, work has continued in collaboration with Dr. Bert Davis of the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, NH. Digital elevation model data (DEM) of the study site in the Sierra Nevada have been purchased from the U.S.G.S. and we are in the process of overlaying the DEM data onto the MAS data, and registering the data sets. Janet Chien/SAIC is performing the registration. After registration is completed, then we will be able to map snow cover by elevation zone. This should allow us to explain some of the differences in snow-surface temperature that have been measured using the thermal-infrared bands of the MAS.

It should be noted that analysis of surface snow temperature is important because the thermal-infrared sensors on MODIS will measure surface temperature. Snow surface temperature is one parameter that is currently used in the snow-mapping algorithm for distinguishing snow from non-snow features.

Analysis of snow reflectance

ASAS. Advanced solid-state array spectroradiometer (ASAS) and Landsat TM data are currently the primary resources that we have for studying snow reflectance. We also use SE-590 hand-held spectrometer data for comparison with the ASAS and TM data. ASAS data were collected at Glacier National Park in February 1992 by the ASAS group led by Jim Irons/Code 923. The ASAS group processed most of the flight lines that were obtained for us and delivered the ASAS data in September 1992. Some ASAS data have been plotted and are discussed, briefly, in the data and interpretation section of this report.

Field work in Saskatchewan - December 1992. During the week of 13 December 1992, Dr. Dorothy Hall/974, Jim Foster/974 and Dr. Glen Liston/USRA/913 (see next section, p.4) went to Prince Albert National Park, Saskatchewan, Canada to acquire field measurements in support of a pre-BOREAS aircraft overflight to support the MODIS/snow, and the passive microwave snow projects. We collaborated with scientists from the Atmospheric Environment Service(AES)/Department of Environment, Canada. Anne Walker and John Metcalfe of AES met us in Prince Albert to make field measurements of snow during a planned overflight of the NASA ER-2 aircraft which was equipped with the MODIS airborne simulator (MAS) and passive microwave instrumentation. Field measurements of snow depth and density were conducted. However, ground measurements of snow reflectance and brightness temperature from observation towers were not successful.

The primary objective of the mission was to acquire airborne and ground-based visible and microwave data to validate algorithms formulated to derive snow cover and snow-water equivalent information. Additionally, higher microwave frequency (>100 GHz) data were to be acquired to determine the usefulness of this part of the spectrum for snowpack studies.

Three crews consisting of two people each obtained measurements of snow depth along pre-determined transects, which were overflown a by a gamma-ray instrumented aircraft from Dr. Tom Carroll's group at the National Weather Service in Minneapolis. The plane flew at an altitude of about 300 m. The NASA ER-2 aircraft was fitted with the MAS, and an AMPR radiometer having the following frequencies available for imaging: 10,19, 37 and 85 GHz. A MIR radiometer was also available to obtain data at frequencies from 89-220 GHz.

Measurements of snow depth and snow-water equivalent were made about every 2 km, using snow tubes and scales. A snow pit was dug at intervals of 10 km where more detailed measurements including temperature, crystal size and soil state (wet or frozen) was made. Temperature probes were inserted into different layers of the snowpack and a lens or loop was used to assess the crystal size and shape. Nearby lakes were measured also; the ice thickness was about 5 cm.

One crew attempted to use a hand-held 37 GHz radiometer to measure snow from a tower in a forested area. The measurements were also to have been made approximately every 5-10 km underneath the aircraft flight lines. Thus we could have compared the 37GHz brightness temperatures as measured on the ground, with brightness temperatures measured from the ER-2. However, due to the extreme cold, the battery did not work and the hand-held radiometer was not providing meaningful results.

Also planned were measurements of snow reflectance using our SE-590 spectrometer which measures reflectance from 400-900nm. However, conditions were cloudy during the time that we were there and no spectrometer measurements were attempted.

It is hoped that a similar set of measurements will be made during the BOREAS Focused Field Campaigns (FFCs). The first FFC is planned for winter of 1994.

Dr. Glen Liston. Glen Liston is currently a USRA visiting scientist working with Dr. Yogesh Sud/Code 913. Dr. Liston received his master's degree from the University of Alaska in 1986 (Dr. Carl Benson was his advisor), and subsequently his Ph.D. from Montana State University. His master's thesis concerned seasonal snow cover on Alaska's North Slope and involved his taking detailed, in-situ measurements of snow. He has been doing sub-grid-scale modeling for the last 2 years in Code 913. His strong interests in snow and ice motivated a collaboration with Dr. Hall/974. Currently, he is planning to help us with BOREAS and related field work and undertake research in support of the snow project to the extent that we can support his efforts. Glen is a major asset to the project.

Boreas participation. The MODIS/snow project is involved in 2 BOREAS projects. The first one is entitled "MODIS land team (MODLAND) algorithm development for boreal forests: participation in BOREAS," S. Running, P.I. The other BOREAS project is entitled "Validation of a passive microwave snow water-equivalent algorithm using an energy balance model," A. Chang, P.I., J. Foster and D. Hall, co-investigators. The proposals are complementary, and involve the use of visible, near-infrared and thermal-infrared as well as passive-microwave data for the purpose of snow extent mapping, analysis of snow reflectance, and determination of liquid-water content of snow. Current plans are for us to participate in the first winter FFC to be held in Prince Albert National Park, Saskatchewan in February 1994.

Data analysis/interpretation

Snow-cover mapping algorithm. We have refined the snow-cover mapping algorithm so that it is more restrictive. The modified algorithm was tested on the Chugach Mountain TM scene and results were compared with results that were obtained using the previous algorithm. Modification of the algorithm consisted of changing the NSDI threshold from 50 to 60. The overall result with the modified algorithm is that fewer pixels are mis-identified as snow. There was an approximately 5 percent decrease in snow-covered area identified with the more restrictive test. In this new test, the threshold for identifying snow was increased. Pixels that changed tended to occur at the perimeters of the snow-covered areas. For a 1024 X 1024 pixel size image, the results of the previous and modified algorithm are shown in Table 1.

Table 1. Snow cover mapping results for a Chugach Mt., Alaska subscene of a TM image

Classification	Previous algorithm	Modified algorithm
sunlit snow	534543	509832
shaded snow	237069	213966
not snow	276964	324778
total	1048576	1048576

ASAS data analysis. Some ASAS data obtained during February 1992 of Glacier National Park, Montana have been studied (Figure 2). Analysis is being done jointly with Jim Irons/923. Preliminary results show that the data acquired parallel to the principal plane of the Sun and in a direction that was oblique to the principal plane of the Sun have higher radiances than the data acquired perpendicular to the principal plane of the Sun. Though not an unexpected finding, ASAS sensor data oriented oblique to the principal plane of the Sun over snow-covered terrain had not been acquired previously. Jim Irons has been developing a method for calculating the reflectance from the ASAS radiance data using the 6S atmospheric code. This will be applied to our data in the near future, then comparison of the simultaneously-acquired, hand-held spectrometer and ASAS data will be accomplished.

Anticipated future actions

In the near future we will compare NOAA AVHRR data of snow cover in Alaska with TM and DMSP/SSMI passive microwave data. Limited TM data are available of central Alaska during the melt period in 1989, 1990 and 1991. We will devise a scheme for assessing the errors using AVHRR and passive microwave data. The current snow-cover mapping algorithm (Figure 1) will be used to map snow using the TM data. Extensive ground-truth data are available from our collaborators at the University of Alaska (Dr. Carl Benson and others). There will be a paper written that will be presented at the Eastern Snow Conference to be held in June of 1993 (see last section for abstract of paper).

The AVHRR data will also be utilized to map snow over other areas of northern North America. Errors in the calculation of snow-covered area will be assessed over sites that are also covered by TM data. In this way, we will begin to devise some of the techniques that will ultimately be used for error assessment using MODIS data.

If MAS data were acquired during the December 1992 test flight of the ER-2 over the Sierra Nevada, as planned, then we will also have the MAS data available for error assessment for comparison with TM data. At this time, it is not known whether or not the MAS data were obtained for us over our proposed flight lines in California. Because of the problems with the ER-2 aircraft, and the need for the aircraft and flight managers to travel to Australia for the TOGA-COARE mission, we may not know about our flight until February.

Papers/Presentations

Dr. George Riggs/RDC presented a paper entitled "Evolution of a snow cover algorithm for the moderate resolution imaging spectroradiometer," by G. Riggs, D. Hall, J. Barker and V. Salomonson, on 7 August 1992 at the ASPRS Convention in Washington, D.C. The full paper was published in the Proceedings of the conference.

Dr. Vincent Salomonson/900 gave a presentation at the COSPAR meeting in Washington, D.C. on 3 September 1992. The title of the presentation was "Snow properties algorithm development for the EOS moderate resolution imaging spectroradiometer."

Two papers were submitted for presentation and publication at the Eastern Snow Conference, to be held in June 1993 in Quebec City, Canada. 1) "Analysis of DMSP/SSMI and ERS-1 SAR data of snow in central and northern Alaska," by D.K. Hall and C.S. Benson, and 2) "The developing moderate resolution imaging spectroradiometer (MODIS) snow cover algorithm," by G.A. Riggs, D.K. Hall, V.V. Salomonson and J.L. Barker.

Abstracts. Abstracts of the above-mentioned papers follow.

Evolution of a snow cover algorithm for the Moderate Resolution Imaging Spectroradiometer (MODIS)

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ABSTRACT

An algorithm for the identification of snow cover is being developed for use with data from the future Moderate Resolution Imaging Sectroradiometer (MODIS), an Earth Observing System (EOS) instrument. The snow cover algorithm currently employs a series of criteria tests, and a normalized snow difference index (NSDI) that identify snow by its reflectance characteristics in the visible and near-infrared regions, and also discriminates between snow and many types of clouds. The snow cover algorithm is being developed with Landsat Thematic Mapper (TM) data and is also being tested with data simulated from TM data to match the 500 m resolution of some of the MODIS bands. Satisfactory snow identification results have been obtained on bright snow targets of test images. Testing of the algorithm indicates that performance of the algorithm is affected by scene characteristics such as: extent of snow, terrain, and types and extent of clouds. Refinements will be required to increase the accuracy and reliability of the snow cover product. Also, discrimination of most types of clouds from snow will be possible with the additional spectral bands from MODIS.

Analysis of DMSP/SSMI and ERS-1 SAR Data of Snow in central and Northern Alaska

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Abstract

Defense Meteorological Satellite Platform/Special Sensor Microwave Imager (DMSP/SSMI) data have been used to map the hemispheric extent of snow cover with a spatial resolution of about 30 km. Because the microwave radiation is emanating from the ground beneath the snow as well as from the snow itself, information on snow depth and liquid water content is often derivable using passive microwave sensors. Similarly, ERS-1 Synthetic Aperture Radar (SAR) data are useful for detecting some changes in snow conditions because of the ability of the SAR signal to penetrate the snow. Studies in Alaska and elsewhere have shown that the relationship between microwave brightness temperature and snow characteristics is complex, and that brightness temperature often cannot be related to snow depth or liquid water content. In this paper, we report results obtained from a study of SSMI data that focuses on central and northern Alaska for the winters of 1988-89, 1989-90 and 1990-91. We also discuss the potential of SAR data for complementing the passive microwave data. Results show variable brightness temperatures which are often apparently unrelated to snow depth and liquid-water content. A persistent anomaly, reported previously, having an unexpectedly low brightness temperature (approximately 45 K lower than surrounding brightness temperatures) is shown to occur in the northern foothills of the Brooks Range in each year of the study. The exact location of the

anomaly changes in different years. Additionally, it is shown that rapidly fluctuating air temperatures and unusually deep snow cover conditions in central Alaska caused unique responses both in the SSMI and SAR data.

The Developing Moderate Resolution Imaging Spectroradiometer (MODIS) Snow Cover Algorithm

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ABSTRACT

Elements of the algorithm for snow cover identification to be implemented with the Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) data which will be available after a 1998 launch, have been developed and tested. This algorithm will be used to produce global and regional snow cover data on a weekly basis. The algorithm utilizes the unique spectral and spatial characteristics of the MODIS to identify snow by spectral reflectance characteristics. In anticipation of the MODIS, the snow cover algorithm is being developed with Landsat TM data and NOAA AVHRR data. The algorithm implements a series of criteria tests and a Normalized Snow Difference Index (NSDI) to identify snow and discriminate snow from many types of clouds. Because of the spatial resolutions of the TM, 30 m for the reflective bands, and 120 m for the thermal-infrared band, it has been possible to identify snow as sunlit or shaded in rugged terrain. The spectral bands of MODIS will also make possible the discrimination of cirrus clouds from snow, a capability that will be utilized in the snow algorithm. The snow cover algorithm has been tested on a variety of Landsat TM scenes with consistent snow identification results. Techniques are being employed to estimate errors using the existing algorithm. The use of the algorithm on a simulated MODIS scene has produced results that are similar to results obtained when the algorithm has been applied to unaltered TM data.

Figure Captions

1. Snow-cover mapping algorithm flow diagram.

2. C-130 ASAS data acquired 26 February 1992 in Glacier National Park, Montana. Radiances for the large view-zenith angles are higher than those for the small view-zenith angles. This is true of the view-zenith angles that were facing the Sun, in this case, lines A and B. Data were acquired when the aircraft was flying parallel to the principal plane of the Sun.